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A Longitudinal Temperature Profile of the Los Angeles River from June through October 2016

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Abstract.—This pilot study developed a longitudinal temperature profile of the Los Angeles River by deploying temperature loggers throughout the watershed between June and October 2016. The watershed was divided into zones based on river system component, urbanization, and channelization. Channelized sites recorded the highest temperatures, tributaries recorded the lowest, and the estuary showed the most fluctuation. Overall, temperatures were too warm to support re-introduction of native fish but currently support non-native fish species. Temperature mitigation is needed for native species to re-establish. Albeit limited in scope, this study establishes a baseline of summer/fall temperatures in the Los Angeles River.

The 82-kilometer-long Los Angeles River (LAR) is an urban river that flows through 14 cities and unincorporated areas in Los Angeles County, California. Approximately 77.25 km of the 82 km main stem of the river is contained in concrete flood control channels, leaving three miles of river with natural channel bottom along the main stem. The soft bottom reaches occur at three locations: the estuary in Long Beach between Willow Street Bridge and the Long Beach Harbor, the Sepulveda Flood Control Basin, and the Glendale Narrows. Tributaries in the upper watershed within the Angeles National Forest, upper Arroyo Seco and Upper Tujunga Wash, remain in a fairly natural state with natural substrate and riparian vegetative cover. When these reaches flow into more urbanized areas, however, they are often channelized as well, with variable levels of natural channel bottom and riparian vegetation remaining depending on flood risk to nearby urban areas.

Currently, native fish species only reside in the upper reaches of the watershed at Big Tujunga Wash and the Arroyo Seco, as well as in the estuary. The obligate freshwater community found in the upper reaches includes arroyo chub (*Gila orcutti*), Santa Ana speckled dace (*Rhinichthys osculus* ssp.), and Santa Ana sucker (*Catastomus santanae*). The freshwater life history form of rainbow trout (*Oncorhynchus mykiss*) is also present in the upper watershed in the Arroyo Seco, but the federally endangered anadromous southern steelhead form of *Oncorhynchus mykiss* was last observed in the LAR watershed in the 1940s (Swift et al. 1993). The Recovery Plan for the extirpated unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*) calls for reintroduction in the LAR watershed[1], while the now state and federally listed endangered Pacific lamprey (*Entosphenus tridentatus*), which was historically found in rivers throughout

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[1] US Fish and Wildlife Service. 1985. Unarmored threespine stickleback recovery plan. USFWS Portland, Oregon.

southern California, has not been observed in the LAR in many years[2]. Currently, numerous non-native fish species, including common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromis niloticus*), green sunfish (*Lepomis cyanellus*), and largemouth bass (*Micropterus salmoides*) are found in the limited soft-bottom areas of the watershed and represent the dominant ichthyofauna of the river reaches that are targeted for major restoration efforts[3,4].

The Los Angeles River is headed for an extraordinary restoration effort[5], but the form and direction of restoration is still under development. Underpinning restoration of the river is the need to understand how the contemporary aquatic community will respond to restorative actions, and to identify barriers to re-establishing native species. Without accurate characterization of the existing instream conditions in priority restoration reaches, the benefits of the multi-billion-dollar effort to revitalize the river will be difficult to determine.

Among the suite of factors that influence distribution and abundance of fish species, water temperature is one of the most important. As ectotherms, the body temperature of a fish is linked to the temperature of the water in which it resides. This means that growth, metabolism, feeding rate, reproduction, and rearing are all tied directly to water temperature. Furthermore, most aquatic organisms, such as benthic macroinvertebrates, that fish rely upon as food sources are poikilotherms, and are also limited by water temperature.

Data on critical thermal temperatures for native fishes historically found in the LAR watershed are limited in the current literature. While increased summer water temperatures tend to be a major limiting factor for most salmonids in other areas, multiple studies conducted in southern California show that rainbow trout (*O. mykiss)* demonstrate more flexibility in their temperature range and an ability to acclimate to higher temperatures within the southern extent of their range (Boughton et al. 2007; Myrick and Cech 2000; Myrick and Cech 2005; Spina 2007). Critical thermal maxima (CTM) ranging from 23°C to 31.5°C have been reported for *O. mykiss* in southern California creeks (Bell 1986; Dagit et al. 2009; Sloat and Osterback 2012). A detailed study of the unarmored threespine stickleback (*G. aculeatus williamsoni*) in the Santa Clara River found CTM for this species was 30.4°C when individuals were acclimated to 8°C, and 34.6°C when acclimated to 22.7°C (Feldmeth and Baskin 1976). Unfortunately, among historically native LAR fishes, these are the only species for which detailed experimental studies on CTM have been published.

While not experimentally derived, field observed temperatures from studies of native fish in the Los Angeles basin and other southern California watersheds can be utilized as indicators of the thermal requirements of target species relative to the conditions currently found in the LAR. For instance, field observations of Santa Ana sucker (*C. santanae*) published by Feeney and Swift (2008) show that larvae may bask in slower flowing areas where temperatures reach 24°C, while juveniles may retreat from warm summer flows (up to 30°C), congregating in cooler areas (15–22°C) near tributary or groundwater sources. Saiki et al. (2007) observed juvenile Santa Ana suckers in June in the Santa Ana River when daytime temperatures averaged 25.3°C, and

[2] CalFish. Accessed on 15 August 2017. http://www.calfish.org/FisheriesManagement/SpeciesPages/PacificLamprey.aspx.

[3] Swift, C. C. and S. L. Drill. 2008. State of the River 2 – The Fish Study. Friends of the Los Angeles River (FoLAR). Los Angeles, CA.

[4] Friends of the Los Angeles River (FoLAR). 2016. State of the River 3: The Long Beach Fish Study. Los Angeles, CA.

[5] City of Los Angeles, Department of Public Works, Bureau of Engineering and US Army Corps of Engineers, Los Angeles District, Planning Division. 2007. Final programmatic environmental impact report/programmatic environmental impact statement. Los Angeles River Revitalization Master Plan. Los Angeles, CA.

ranged to 30.8°C, as well as in September in the San Gabriel River when temperatures averaged 19.6°C (range 15.0–22.9°C). USFWS[6] reported mortality events for Santa Ana suckers when temperatures exceeded 32.8°C in the Santa Ana River and 26.7°C in Big Tujunga Creek.[6] In a survey of the upper San Gabriel River from 2007 and 2008, O'Brien et al. (2011) reported mean daily temperatures of ~21°C in the north and east forks of the San Gabriel River and ~20°C in the west fork. This study reported Santa Ana sucker, rainbow trout, and Santa Ana speckled dace in all three forks of the San Gabriel River, while arroyo chub were only found in the east and west forks (O'Brien et al. 2011). While arroyo chub are physiologically adapted to survival in habitats with wide temperature fluctuations (Castleberry and Cech 1986), they are most commonly found in low gradient streams where water temperatures do not exceed 28°C, and where spawning temperatures ranging from 14–22°C are available (O'Brien 2009; Moyle et al. 2015). Moyle et al. (1995) found that Santa Ana speckled dace prefer perennial streams fed by cool springs that maintain summer water temperatures below 20°C.

Even though much of the LAR has been channelized, there are still areas with natural substrate that could potentially provide suitable habitat for native fish (i.e. Glendale Narrows, Sepulveda Basin). The lack of concrete lining at these locations accommodates groundwater upwelling, which provides refugia habitat that currently support both non-native fishes as well as native amphibians absent in concrete reaches of the LAR[7]. Since water temperature is so closely tied to the distribution and abundance of fish species at various life stages and with that of their prey animals, a longitudinal temperature profile of the river can be used as an indicator of habitat quality on the watershed scale (Poole et al. 2001a). Determining where water temperature in the LAR is currently suitable for native fish is an important first step for any proposed restoration effort. If temperatures are in fact suitable for native species, then future efforts can focus on targeted in-stream and riparian habitat restoration, non-native species management, or other non-temperature related actions. If temperatures in the river are not suitable for native species, future restoration efforts should be developed with a focus on improving the temperature regime of the river for native fishes.

A study to capture a detailed thermal profile of the LAR was initiated in early 2016, with installation of continuously recording temperature data loggers at 13 sites throughout the watershed. Temperature data was recorded from June through October 2016. The intent of the study was threefold: to characterize temperatures throughout the watershed; to document current baseline conditions at representative locations during the most stressful summer conditions; and to identify opportunities for restoration of native fish habitat. While limited in scope, the present study provides an initial, albeit incomplete, picture of baseline summer/fall temperatures in the LAR against which future studies and conditions can be compared.

Materials and Methods

The study area includes the main stem and three major tributaries of the LAR, from its headwaters in the Angeles National Forest and western San Fernando Valley, to the estuary in Long Beach (Fig. 1). For comparison purposes, the watershed is divided into six zones based on river component (tributaries: A, C, E; mainstem: B, D, and estuary: F). Tributaries within

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[6] US Fish and Wildlife Service. 2014. Draft recovery plan for the Santa Ana sucker. USFWS Pacific Southwest Region, Sacramento, CA.

[7] Swift, C.C. and J. Seigel. 1993. The past and present freshwater fish fauna of the Los Angeles River, southern California, with particular reference to the area of Griffith Park. in The biota of the Los Angeles River: an overview of the historical and present plant and animal life of the Los Angeles River drainage. (K. Garrett, ed.) Los Angeles Natural History Museum Foundation, Los Angeles, CA, 28 pp.

Fig. 1. Study Area showing zones and temperature logger locations.

a geographic region are ascribed their own zones and the main stem was further divided into natural (B) and channelized sections (D). Sites representative of depth and canopy cover were chosen within each zone and temperature loggers were installed at 13 locations in May 2016 (Fig. 2). Sites were selected based on the following criteria: accessibility, safety, location with respect to soft bottom reaches, depth, canopy cover, and tributary inputs, and distribution along the river (Table 1).

Water temperature data was collected from June through October 2016 using a combination of ONSET HOBO TidbiT v2 Water Temperature Data Loggers and HOBO Pendant Temperature Data Loggers (collectively, HOBOs) programmed to record time, date, and temperature. The TidbiT v2 has an accuracy of $\pm 0.21°C$ and the Pendant has $\pm 0.53°C$ accuracy; both are designed for use in outdoor and underwater environments. The study period was selected to align with southern California's dry season, with the highest air temperatures and lowest precipitation, when thermal stress on fish would be most likely to occur.

All loggers were prepared for deployment in the water column with appropriate site-specific materials to anchor them in place depending on site conditions (substrate, vegetation, access, etc.) and water depth. At all sites, the loggers were crimped to one end of an approximately one-meter long line of 90 lb-test stainless steel trolling wire using 1.40 mm leaden sleeves. The method used to anchor the other end of the wire to the stream channel varied depending on site

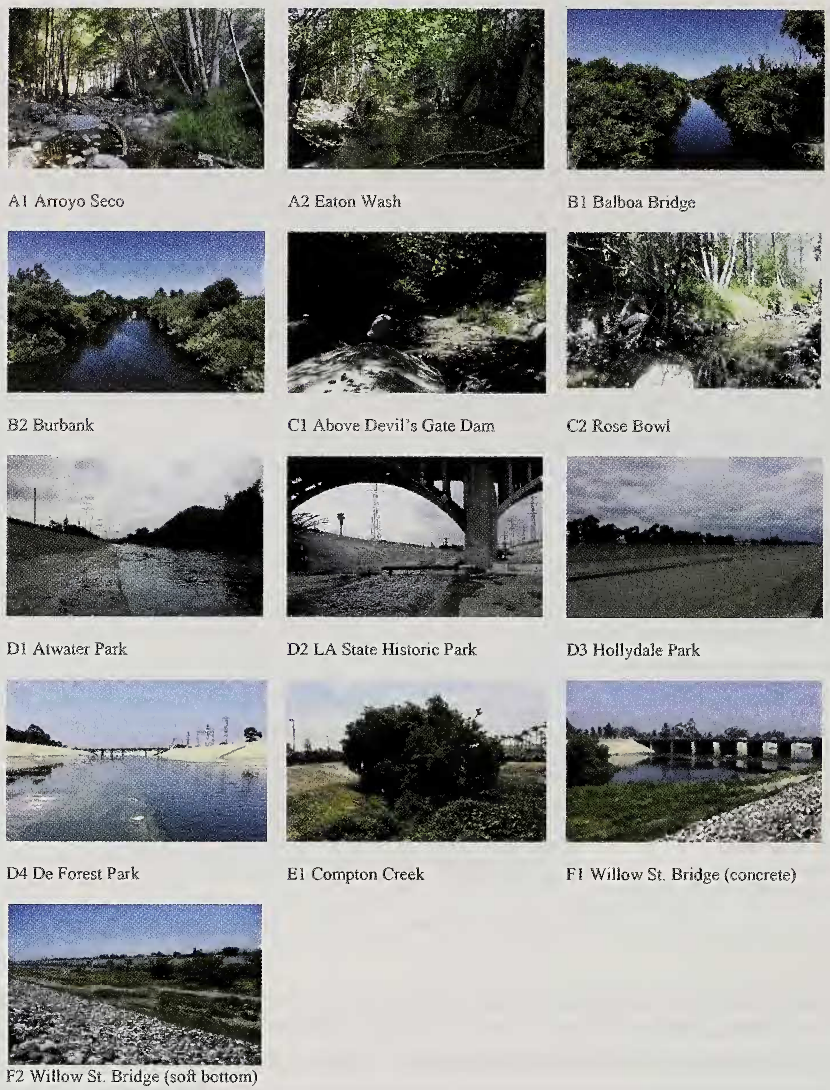

Fig. 2. Photograph panel of Los Angeles River study sites June–October 2016.

conditions. For natural flow areas with mature vegetation, the devices were secured to a tree trunk, root, boulder or other stable object at the water's edge in such a way as to allow the logger to hang near the bottom of the water column while keeping it out of plain sight in order to reduce incidents of vandalism. For concrete channels and other areas where the previous method was not feasible, loggers were bolted to the channel wall. Weights were added to all wires to help prevent loggers from being swept up on shore during high flow events. Data loggers were not enclosed in protective housing, were of similar coloration to the surrounding substrate, and were only protected from direct sunlight where sufficient riparian vegetation was present to provide shading.

Locations in Zone A were managed by the Council for Watershed Health through their Los Angeles River Watershed-wide Monitoring Program. Both sites in Zone A had one HOBO in

Table 1. Site characteristics of the Los Angeles River water temperature monitoring locations.

Zone	Region	Site	Location	Channel type	Logger depth (in)	Distance from river mouth (mi)	Reach type	Data range
A	Angeles National Forest	1	Arroyo Seco	Soft Bottom	8	39.92	Tributary	Jun–Oct
		2	Eaton Wash	Soft Bottom	5	35.66	Tributary	Jun–Oct
B	Western San Fernando Valley	1	Balboa	Soft Bottom	30	45.9	Main Channel	Jun–Oct
		2	Burbank	Soft Bottom	20	44.4	Main Channel	Jun–Oct
C	Arroyo Seco	1	Above Devils Gate Dam	Soft Bottom	4	36.2	Tributary	Jun–Oct
		2	Rose Bowl	Soft Bottom	12	31.8	Tributary	Jun–Oct
D	Glendale Narrows	1	Atwater Park	Soft Bottom	24	30.5	Main Channel	Jun–Aug
	Downtown Los Angeles to Rio Hondo	2	L.A. State Historic Park	Concrete	24	24.4	Main Channel	Jun–Jul
		3	Hollydale Park	Concrete	24	12.1	Main Channel	Jun–Oct
	Compton to Dominguez Gap	4	DeForest Park	Concrete	24	8.0	Main Channel	Jun–Oct
E	Compton Creek	1	Compton Creek	Soft Bottom	20	8.8	Tributary	Jun–Sep
F	Long Beach Estuary	1	Willow St. Bridge	Concrete	20	3.7	Main Channel	Jun–Oct
		2	Willow St. Bridge	Soft Bottom	20	3.6	Main Channel	Jun–Oct

Table 2. Summary of potential and missing data points (148 days) at each site for the study period of June 4, 2016 at 12:00 to October 30, 2016 at 18:00.

	A1	A2	B1	B2	C1	C2	D1	D2	D3	D4	E1	F1	F2
Potential Data Points	886	886	7117	7117	7117	7117	7117	7117	7117	7117	7117	7117	7117
Missing Data Points	99	20	197	196	98	1	3515	5184	7	21	2140	1	57
Missing Data Days	12	4	4	4	2	0	73	108	0	0	45	0	1

the water recording temperature every four hours and one HOBO outside the water recording air temperature at the same four-hour interval. Data recorded at these sites were provided in a Microsoft Excel file for comparative analysis. Locations in Zones B-F had one HOBO per site recording water temperature at 30-minute intervals. Each site was visited monthly by trained citizen science volunteers to download the recorded data, ensure loggers were secure, and photograph site conditions. Data from each logger was offloaded using a HOBO U-DTW-1 Waterproof Shuttle Data Transporter in the field, which was subsequently uploaded to a computer using Hoboware PRO software, then compiled in a Microsoft Excel database.

Data points available at each site varied due to environmental factors affecting temperature readings (e.g. dry-downs, washouts, etc.), theft or vandalism, and equipment malfunction. These factors affected both the thermometer's ability to record data and its ability to take data representative of river conditions. Of all potential data points, less than 15 percent were absent for the entire study period across all sites. The majority of missing data occurred at sites D1, D2, and E1 (Table 2).

Water temperature data recorded from study reaches were summarized to establish a daily maximum, minimum, and mean temperature for each site. These daily metrics were combined to establish monthly mean, maxima, and minima. Temperature metrics were compared between study sites: 1) to examine differences between concrete and natural bottom locations; 2) to examine differences between sites in the main stem and tributaries; 3) to calculate the frequency, time of day and duration when temperatures exceed thermal limits for target native fish species; and 4) to map the changes in temperature throughout the river.

A quality assurance/quality control process to ensure data accuracy included several levels of review. The first level occurred when HOBO readings were imported into Microsoft EXCEL, and included completeness and examination for unusual outliers or missing information. Then, difference in temperature readings between consecutive data points was analyzed in an effort to differentiate between natural extreme changes in temperature, unnatural extreme changes in temperature representative of river conditions, and unnatural extreme changes in temperature that are not representative of river conditions (HOBO being handled or out of water during temperature recording). Table 2 summarizes the completeness of data collected between June and October 2016.

Precipitation and daily minimum and maximum air temperature records were obtained from five different NOAA weather stations throughout the Los Angeles basin. Daily flow data was obtained from Los Angeles County Department of Public Work's eight gauging stations in the Los Angeles basin. Weather stations and stream gauges are mapped in Fig. 1. The data obtained was examined for relationships with water temperature. Correlations between daily maximum water temperatures and daily maximum air temperatures and flow measurements were determined independently for each site. Daily maximum air temperatures showed a high degree of collinearity (not shown), so subsequent analyses utilized daily maximum air temperature from the Mount Wilson weather station. The sole exception was site C1, at which daily maximum water temperatures showed the highest correlation to air temperature data from the Long Beach weather station. Data from the flow and weather station with the highest correlation coefficient for each site was used in a multiple regression with daily maximum water temperature as the dependent variable. All analyses were performed in R[8].

Results

Between June and October 2016, the highest daily maximum water temperatures occurred in mainstem concrete bottom reaches (D2, D3, D4), while lower temperatures occurred in tributary reaches with more natural substrate and riparian vegetation (A1, A2, C1, C2, E1) (Fig. 3). Site D1, along the main stem with natural substrate and concrete banks, exhibited the highest daily maximum temperatures particularly in June and July. Less urbanized sites B1 and B2 in the Sepulveda Basin showed moderate daily maximum temperatures compared to other sites, while the estuary sites (F1 and F2) demonstrated more variability in maximum daily temperatures across the season than other sites, probably due to tidal influence. At site F2, overnight high temperatures are in close coordination with late night high tides.

The maximum water temperatures observed in all study sites are shown by month in Table 3. Monthly maximums were lowest in tributaries (Zones A, C, E). Highly urbanized main stem sites recorded the highest maximums (Zone D), and less urbanized main stem areas were mid-range (Zone B). Maximum temperatures showed the widest range in June, with readings ranging from 20.6°C to 36.8°C. Channelized sites D1 and D2 reached their highest temperatures in the month of June, while channelized sites D3 and D4 reached their highest temperatures in July. The highest single temperature reading of the season was recorded at the Long Beach Estuary site F1 in August. The other estuary site F2 also experienced its highest temperature during the month of August. Compton Creek E1 was the only site to record its highest maximum temperature in September.

Zone B sites had the most consistent monthly maximums. All other sites showed more variation in maximums from month to month. The most extreme monthly maximum variation occurred at site C1 with monthly maximums of 20.9°C, 22.1°C, 36.7°C, 25.4°C, 33.3°C occurring in June through October respectively. However, this was the shallowest site, and dry downs were a continuous issue, requiring relocation of the logger on multiple occasions throughout the study period. The highest temperatures recorded at C1, therefore, are most likely due to water receding to such extent that the logger recorded air temperature for some time before being relocated to a deeper pool.

Overall, monthly minimum water temperatures show less variation across sites than monthly maximums (Fig. 4). Sites B1 and B2 in Sepulveda Basin had the highest minimum temperatures, but also had the smallest monthly ranges (3.6–7.1°C) and recorded relatively cool maximums compared to other sites. In sites with concrete bottoms, the range between monthly maximum and minimum is greater (13.2–20.1°C). Zone A sites in the Angeles National Forest consistently had the lowest minimums throughout the season followed by site C1 (a fairly remote and natural tributary reach just downstream of A1). A short distance downstream, site C2 also recorded relatively low minimums during June and July. The lowest mean water temperatures were recorded in tributary sites A1, A2, C1, C2, and E1. Sites B1 and B2 in the less heavily urbanized Sepulveda Basin portion of the study area had the highest monthly averages and the smallest ranges of temperatures between monthly maximum and minimum.

[8] R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

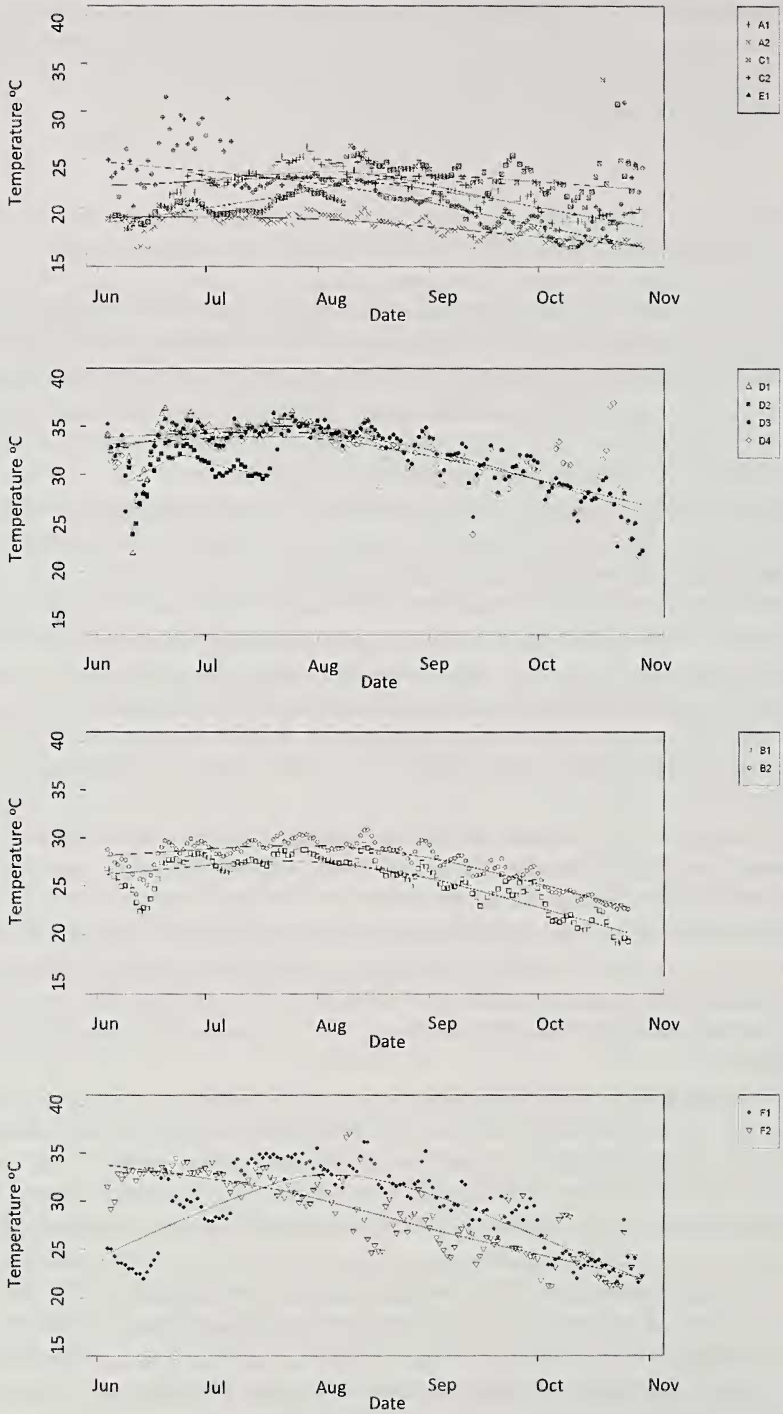

Fig. 3. Daily maximum temperatures at all sites plotted by date between June – October 2016. Smoothed lines are shown.

Table 3. Maximum water temperatures (max), minimum water temperatures (min), and range between maximum and minimum water temperatures each month (range). Highest maximum water temperatures for each month shown in bold; highest maximum water temperature for each site underlined.

	June			July			Aug.			Sept.			Oct.		
Site	Max	Min	Rng	Max	Min	Rng	Max	Min	Rng	Max	Min	Rng	Max	Min	Rng
A1*	23.7	17.2	6.5	26.3	16.7	9.6	25.8	15.8	10.0	23.5	13.7	9.8	19.9	13.8	6.1
A2*	20.6	13.7	7.0	19.9	14.0	5.8	19.9	13.8	6.1	18.5	13.8	4.8	17.7	13.5	4.2
B1*	28.4	21.2	7.1	28.7	25.1	3.6	29.3	23.8	5.5	26.7	21.7	5.0	24.8	18.4	6.3
B2*	29.9	22.8	7.0	30.5	25.9	4.6	30.8	25.5	5.4	29.3	23.3	6.0	26.3	19.9	6.4
C1*	20.9	15.2	5.7	22.1	17.8	4.4	36.7	16.0	20.7	25.4	14.4	11.0	33.3	13.4	20.0
C2*	31.5	14.4	17.1	31.3	17.8	13.5	26.2	19.7	6.5	21.6	17.2	4.4	31.0	15.1	15.9
D1*	**36.8**	17.1	19.7	**36.5**	19.8	16.8	35.5	19.1	16.5	-	-	-	-	-	-
D2	33.2	20.0	13.2	31.5	23.5	8.0	-	-	-	-	-	-	-	-	-
D3	35.7	17.2	18.6	36.4	20.6	15.7	35.6	19.8	15.8	**33.8**	17.4	16.4	31.3	17.0	14.3
D4	35.6	16.7	18.9	35.7	20.4	15.3	34.9	19.5	15.4	33.3	17.0	16.3	**33.4**	13.2	20.1
E1*	26.4	16.5	9.9	25.0	19.7	5.4	26.8	19.6	7.2	29.5	17.7	11.8	-	-	-
F1	33.3	20.9	12.4	34.9	20.3	14.6	36.1	19.6	16.5	32.1	17.5	14.6	28.0	17.5	10.5
F2*	34.4	21.3	13.1	34.0	20.2	13.8	**37.0**	18.6	18.4	30.6	17.5	13.1	28.6	15.4	13.1

* indicates natural bottom location

Hourly variation is shown in Fig. 5. Throughout the study period, the coolest temperatures in the LAR were recorded in the early morning, between 06:00 and 08:00, except for site F2 whose coolest hour on average was 11:00 (Table 4). The highest temperatures occurred between 13:00 and 20:00, with the majority of sites peaking between 14:00 and 16:00. Greater diurnal variation occurred in highly urbanized zones at D2, D3, E1, and F1, while diurnal variation was much diminished in more natural sites with soft bottoms and riparian vegetation such as sites A1, A2, C1, and C2. In the less urbanized Sepulveda Basin in the San Fernando Valley region, sites B1 and B2 were warmer overnight throughout the whole season. Average nighttime (17:00–05:00) temperatures were 0.53°C warmer than average daytime (05:00–17:00) temperatures at site B1 and 0.86° warmer at site B2. This pattern of warmer overnight temperatures was also observed at the estuary sites F1 and F2. Nighttime temperatures were 3.07°C warmer than daytime temperatures at F1, and 0.95°C warmer at nighttime than daytime at F2 throughout the study period.

The highest seasonal water temperatures occurred in the most heavily developed portions of the watershed, namely D1, D2, D3, and D4, all with average maximum temperatures for the season topping 30°C (Table 5). Site D1 had the highest temperatures of the season (average maximum $T = 34.1$°C). This site has a natural substrate bottom but concrete lined banks. This site also demonstrated the largest difference between average maximum and average minimum temperatures during the study period. The lowest temperatures in the watershed were recorded in Zone A, a relatively natural portion of the watershed found within the Angeles National Forest. The main stem channel reaches in the Sepulveda Basin (B1 and B2) showed the most stability with a 1.4° and 2.3° difference between seasonal average maximum and seasonal average minimum temperatures. Fig. 6 illustrates these temperatures in a longitudinal profile throughout the watershed to highlight thermal barriers to movement of native fishes from headwaters to the ocean and vice versa.

The changes in water temperature along the longitudinal continuum of the river from headwaters to estuary are illustrated in Fig. 7. The range of temperatures at each site are plotted

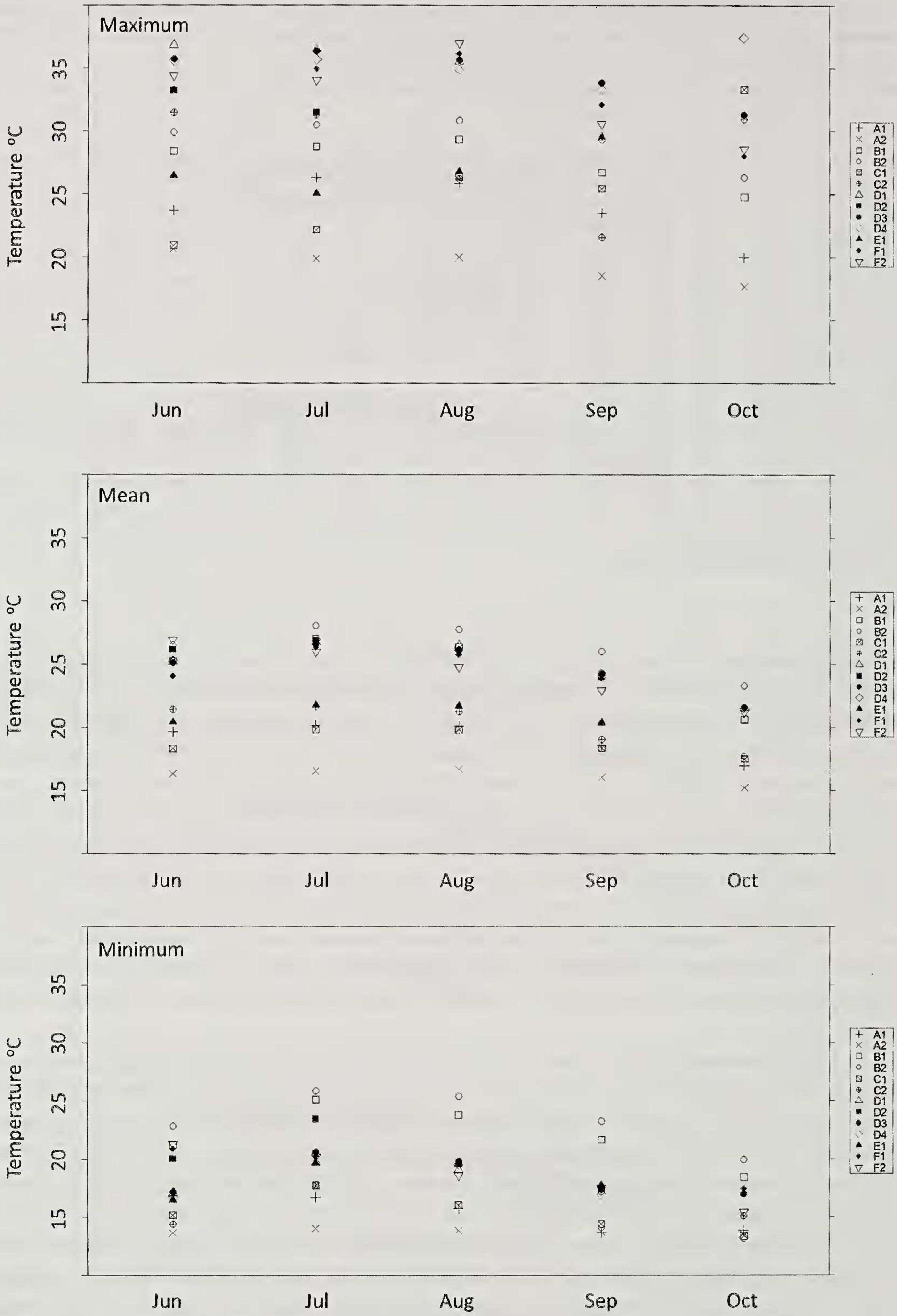

Fig. 4. Monthly maximum, mean, and minimum water temperatures taken at 13 sites in the Los Angeles River between June–October 2016.

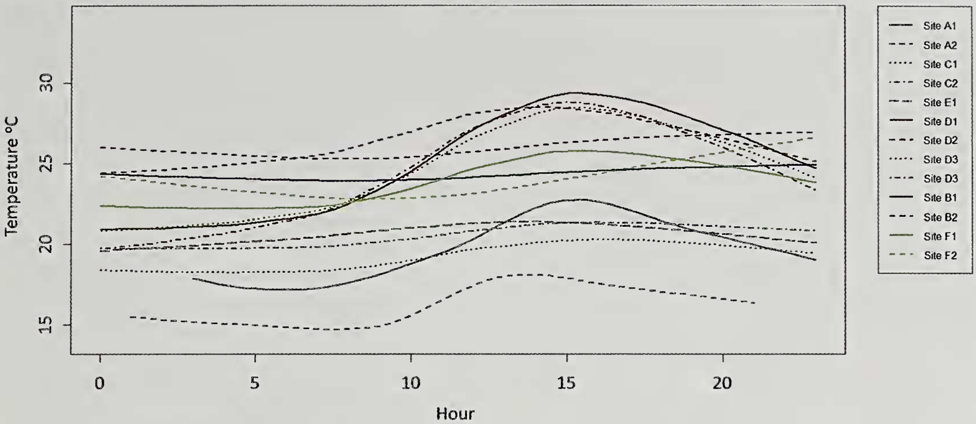

Fig. 5. Average hourly temperatures of 13 sites in the Los Angeles River between 4 June 2016 at 12:00 and 31 October 2016 at 18:00. Lines are smoothed over individual hourly points.

against the estimated temperature over which *O. mykiss* begin to show signs of behavioral stress (24°C). Although other target native fish species may be able to tolerate higher temperatures, 24°C was selected as the thermal limit because it would protect the majority of life stages of most native fish species. Apart from the headwaters that already support native fishes, most of the LAR surpasses this threshold, creating thermal barriers that could prevent movement from headwaters to the ocean and vice versa, access to refugia, and even year-round survival of native fish species.

Maximum daily water temperature from all sites, with the exception of C1, showed a significant positive correlation with maximum daily air temperature from the Mount Wilson weather station in the multiple regression (Table 6). Sites D2 and D3 showed the highest correlation coefficients, while sites C2 and F2 had the lowest. Maximum daily temperature from site C2 had a non-significant positive correlation with maximum daily air temperature from the Long Beach weather station. Five sites had a significant negative correlation with flow measured at Los

Table 4. Timing of maximum and minimum average hourly temperatures at sites in Los Angeles River June through October 2016.

	Max		Min	
Site	Time	°C	Time2	°C2
A1	13:00	18.00	9:00	14.93
A2	15:00	21.95	7:00	16.93
B1	19:00	25.43	8:00	24.19
B2	18:00	27.49	8:00	25.36
C1	14:00	21.36	7:00	17.37
C2	16:00	21.35	7:00	19.24
D1	15:00	33.93	7:00	20.77
D2	14:00	30.09	6:00	23.76
D3	16:00	31.28	7:00	20.65
D4	15:00	31.24	6:00	20.01
E1	15:00	22.24	6:00	20.44
F1	16:00	28.63	7:00	21.25
F2	20:00	26.59	11:00	23.00

Table 5. Seasonal average maximum, mean and minimum temperatures at each site from June 4, 2016 to October 30, 2016.

Site	Site name	Max	Mean	Min	Notes
A1	Arroyo Seco	21.9	19.1	16.9	Natural channel and banks; upper watershed tributary
A2	Eaton Wash	18.0	16.2	14.8	Natural channel and banks; upper watershed tributary
B1	Balboa	25.6	24.8	24.2	Deep and wide soft bottom reach with natural riparian vegetation on mainstem
B2	Burbank	27.6	26.4	25.3	Deep and wide soft bottom reach with natural riparian vegetation on mainstem
C1	Above Devils Gate Dam	22.0	18.8	17.3	Natural channel and banks; native riparian vegetation; shallow tributary upstream of Devil's Gate Dam.
C2	Rose Bowl	21.8	20.2	19.0	Soft Bottom with riparian vegetation; tributary in urbanized area downstream of Devil's Gate Dam and the Rose Bowl.
D1	Atwater Park	34.1	26.2	20.7	Soft bottom. Just upstream of Glendale Water Reclamation Plant. Some riparian and in-channel vegetation.
D2	L.A. State Historic Park	30.5	26.5	23.7	Concrete channel in heavily urbanized area. No vegetation.
D3	Hollydale Park	31.9	24.8	20.5	Concrete channel in heavily urbanized area. No vegetation.
D4	DeForest Park	31.6	24.8	19.9	Concrete channel in heavily urbanized area. No vegetation.
E1	Compton Creek	22.8	21.2	20.2	Soft bottom, tributary reach in urbanized area with riparian vegetation.
F1	Willow St. Bridge	29.2	24.4	21.1	At end of concrete channel entering estuary.
F2	Willow St. Bridge	28.7	24.3	21.1	Soft bottom estuary.

Angeles County Burbank-Western Storm Drain station E285F. Site E1 had a positive correlation with flow data, but this value was not statistically significant.

Discussion

In streams like the Los Angeles River that are maintained for flood control, channelization can be a strong driver of the thermal regime. Simplifying the physical structure of the river channel eliminates natural thermal buffers and insulators (Poole and Berman 2001), causing water temperature to be vulnerable to fluctuations in ambient air temperature and solar radiation. Confining a stream to a concrete channel also eliminates the stream's connection with groundwater, resulting in loss of the natural buffering effect that groundwater has on stream temperatures. In addition, concrete lining on the streambanks absorbs solar energy and radiates heat due to the thermal mass of the construction materials (Hester and Doyle 2011).

Land use activities that increase impervious surfaces outside the stream channel also alter the amount of water flowing into the stream and its timing and temperature (Poole et al. 2001a; 2001b). High temperature pulses can occur in urban streams because runoff from impervious surfaces can result in highly variable temperatures over short time scales (Van Buren et al. 2000). During the winter months, stormwater runoff accounts for the majority of the water flowing through the concrete channels designed for flood control, but flow into the LAR during our study period from June to October was mostly comprised of non-point source “urban drool”

Fig. 6. Los Angeles River seasonal average maximum temperatures from estuary to headwaters.

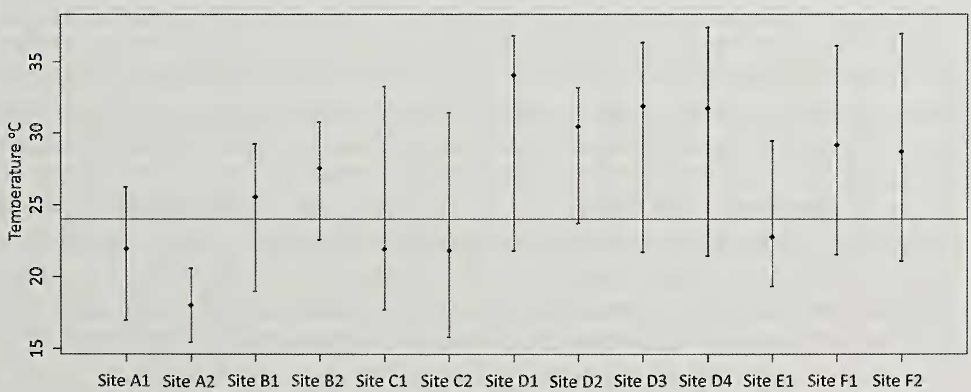

Fig. 7. Temperature ranges for sites in the Los Angeles River June–October with thermal limit of 24°C for target native fish species.

Table 6. Correlation coefficients between maximum daily water temperature and maximum daily air temperature/flow in the Los Angeles River. All air temperature data was from the Mount Wilson weather station unless indicated. Multiple R^2 from the multiple regression is also reported.

Site	Max. air temp.	Flow[a]	Multiple R^2
B1	r = 0.646***	r = −0.202; F252	0.417
B2	r = 0.676***	r = −0.208; F252	0.457
C1	r = 0.220[b]	r = −0.434***; E285	0.199
C2	r = 0.350***	r = 0.350***; E285	0.305
D1	r = 0.633***	r = −0.558**; F252	0.532
D2	r = 0.751***	r = 0.436***; F300	0.588
D3	r = 0.738***	r = −0.299**; E285	0.569
D4	r = 0.734***	r = −0.304**; E285	0.565
E1	r = 0.448***	r = 0.243; F319	0.231
F1	r = 0.614***	r = −0.482***; E285	0.512
F2	r = 0.430***	r = −0.218; F319	0.199

[a] Flow data from the station used in the multiple regression is reported after the correlation coefficient.
[b] Daily maximum air temperature data from the Long Beach weather station.
** Indicates variable was significant in the multiple regression with $p < 0.01$
*** Indicates variable was significant in the multiple regression with $p < 0.001$

surface runoff, runoff from very minor rain events (less than 1-inch total in most areas over the watershed during the study period), and releases from water treatment facilities. Releases from water reclamation plants account for the majority of the LAR's base flow and could play a key role in regulating water temperatures. The Donald C. Tillman Water Reclamation Plant, a leading producer of reclaimed water in the San Fernando Valley, releases approximately 80 million gallons of tertiary treated water per day into the LAR basin. Treated water is distributed to three nearby lakes (the Japanese Garden Lake, the Wildlife Lake, and the Balboa Recreation Lake) and directly into the LAR just above site D1. The Los Angeles/Glendale Water Reclamation Plant processes an additional approximately 20 million gallons a day to tertiary standards, and releases water to the LAR just downstream of D1[9].

By comparing different sites within the same system that are subject to varying conditions of concrete channelization, urbanization, riparian cover, and flow augmentation, we began a rudimentary isolation of specific effects on maximum, minimum, and mean water temperatures, and their influxes and ranges longitudinally through the watershed. We found that the smallest range of water temperatures occurred in the upper watershed in the Sepulveda Basin of the western San Fernando Valley, where the channel has a soft bottom, significant depth and width, and extensive riparian vegetation lining the banks and overhanging the wetted channel. While the natural conditions of this reach seem to moderate water temperatures from extreme fluctuations, the overall temperatures of the two sites (B1, B2) remained high. Water temperatures in July never dropped below 24°C, which is often considered the lower limit of the critical thermal maxima for *O. mykiss* (Boughton and Palmer 2007; Boughton et al. 2015; Myrick and Cech 2000; Myrick and Cech 2005; Spina 2007; Sloat and Osterback 2012; Table 7). Throughout the entire study period, only 36% of days at site B1 and 27% of days at site B2 did not exceed 25°C.

[9] LA City Department of Sanitation. 2017. Los Angeles-Glendale water reclamation plant. Available from www.lacitysan.org/, Accessed 1 May 2017.

Table 7. Reported thermal limits for target native fish species.

Scientific name	Common name	Max. temp.	Source
Catastomus santanae	Santa Ana sucker	22°C, 26.7°C – 32.8°C	Moyle 2002, USFWS 2014
Gasterosteus aculeatus williamsoni	unarmored threespine stickleback	30.4°C – 34.6°C	Feldmeth and Baskin 1976
Oncorhynchus mykiss	rainbow / southern steelhead trout	23°C – 31.5°C	Bell 1986, Boughton et al. 2007, Boughton et al. 2015, Myrick and Cech 2000, Myrick and Cech 2005, Spina 2007, Sloat and Osterback 2012
Gila orcutti	Arroyo chub	28°C	O'Brien 2009, Moyle et al. 2015
Rhinichthys osculus ssp.	Santa Ana speckled dace	20°C	Moyle et al. 1995

Downstream in the main stem of the river near D1, the water temperature range expanded, with differences in monthly maximum and minimum temperatures ranging from 16.5 to 19.7°C. The natural bottom site is located downstream of a long stretch of simplified concrete channel surrounded by multi-lane State Highway Route 5 and miles of impervious surfaces that are devoid of thermal buffers and insulators, save a small amount of heavily managed in-channel and riparian vegetation. The concrete bank itself radiates absorbed solar energy as well (Van Buren et al., 2000). The monthly minimums and maximums at D1 were all more extreme than those observed in Zone B (B1, B2). D1 recorded monthly maximums in the mid-30s in June, July and August, and monthly minimums in the teens, whereas in Zone B monthly maximums did not exceed 30.8°C and minimums did not drop below 21°C in the same months.

Water from tributary reaches in Zones A (A1, A2) and C (C1, C2) enters the mainstem of the LAR between sites D1 and D2. Water temperatures at all sites in Zones A and C were lower than those in the mainstem. The two sites in the Angeles National Forest (A1, A2) had the lowest temperatures overall, while the two Arroyo Seco tributary sites (C1, C2) also remained cooler than the main stem locations, although warmer than the sites in Zone A. As expected, water temperatures increased as the tributary neared the urban center, and the influence of impervious surfaces and urban runoff increased. Intact riparian vegetation and substantial canopy cover at site C2 is likely responsible for helping to moderate temperatures despite being surrounded by urban development, although that effect was not evident in the Sepulveda Basin sites (B1 and B2) where despite well developed riparian bank cover, temperatures remained high with little variation in range from maximum to minimum. Lower temperatures at site D2 as compared with D1 indicate that an inflow of cooler water from the Arroyo Seco tributary may impact water temperature at that location, although there is not yet sufficient data to confirm this hypothesis.

Theft or loss of thermometers in the highly visible concrete channels resulted in limited data sets for a large geographic area along the central main stem of the river. Despite the limited data, trends appear to be consistent in the main channel between sites D1 and D4. The highest daily and monthly maximum water temperatures consistently occurred in Zone D. Zone D also experienced greater diurnal variation. The water temperatures in this zone showed a strong correlation to air temperatures, indicating that, lacking vegetation, substrate, and groundwater influence, the water temperatures in these concrete channels are easily influenced by fluctuations in air temperature.

The 13.6 km-long Compton Creek is a highly urbanized subwatershed that enters the LAR channel between sites D4 and F1. The upper 9.3 km of this tributary is contained within a concrete box channel, while the remaining lower 4.3 km has a soft bottom, native riparian vegetation, and concrete sides. Site E1 is located within this lower soft-bottom reach of the tributary. Although heavily influenced by impervious surfaces and urban runoff, E1 demonstrated lower temperatures than those of the mainstem sites, further emphasizing the important role of intact riparian vegetation, canopy cover, and groundwater interactions on stream temperature.

Nearing the river mouth, the sites at the Long Beach Estuary (F1, F2) showed unusual trends. Despite being placed 0.16 km apart and having the widest channels in the study area with potentially more thermal holding capacity, the influence of the concrete channel closer to site F1 compared to the more tidally influenced site F2 resulted in water temperature peaks at much different times. Maximum average hourly temperatures at site F1 occurred at 16:00 and minimum average hourly temperatures occurred at 07:00, which is consistent with the hourly fluctuations of sites further upstream. At F2, however, maximum average hourly temperatures peaked at 20:00 and minimum average hourly temperatures occurred at 11:00 suggesting that tidal fluctuations could also have played a role in the timing differences in temperature extremes. At site F2, late night high tides were in close coordination with overnight temperature peaks, which was not the case at site F1, a shallower site with less salt water or stratification.

Conclusions

Using the estimated thermal limit of 24°C, water temperatures throughout the mainstem of the Los Angeles River would be exceedingly challenging for key native fish species such as rainbow/steelhead trout, arroyo chub, Santa Ana sucker, and Santa Ana speckled dace (Table 7). Although the water temperatures are cooler during the winter migratory season, the current temperature regime creates thermal barriers for fish movement through the watershed during the warmer summer season and isolates current populations of native fish to the tributaries in the Angeles National Forest where temperature only exceeded 24°C for 19% of days in the study period at A1, but never at A2. While currently the extreme temperatures do support a wide range of non-native generalist fish species in the mainstem, summer season temperature mitigation is imperative for the reintroduction of native fishes. Even though some native fish species are able to survive temperatures close to 30°C, they all require cooler temperatures for successful reproduction and juvenile rearing.

Comparison of channelized to non-channelized reaches suggests that channelization widens the temperature range (higher maximum, lower minimum). The most natural tributaries in the Angeles National Forest recorded the lowest temperatures overall. However, channels with natural substrate and riparian vegetation exhibited temperatures in the mid-range as they entered increasingly urban areas having more impervious surfaces near the stream channel. Mainstem sites with concrete banks and bottoms as well as site D1, with concrete banks and a soft bottom experienced the most temperature fluctuation. Lack of shade that would be provided by overhanging vegetation on natural banks; lack of connection with groundwater to moderate the temperature of surface flow; and the capacity of concrete structures to absorb and re-radiate solar energy all contribute to an increased temperature range. The role of continuous input of tertiary treated waters into the LAR should be further examined. Since the temperature of released wastewater effluent is consistent year-round, it is conceivable that the warming effect caused by released effluent in the cool winter months may have the reverse effect in the warmest part of the year, actually cooling instream temperatures and providing refugia for aquatic species.

Although this paper is limited in scope, our study points to both channelization in the mainstem and the heat island effect created by surrounding urbanization as major sources of thermal stress in the Los Angeles River watershed. However, further studies with more loggers over a longer period would be necessary to isolate heat sources and understand their synergistic effects. Use of more sophisticated monitoring technologies, such as fiber optic sensors and thermal infrared remote sensing, would further the scientific understanding of the thermal regime of the river. Additionally, it is important to remember that reach scale restoration can work to de-channelize sites, but the restored stream may still be degraded (Purcell et al. 2002) due to other stressors such as dissolved oxygen. Further investigation of dissolved oxygen levels related to temperature and flow patterns throughout the river are needed as well. If reach scale restoration is to be successful it must be implemented as part of a larger strategy that works to mitigate the effects of underlying stressors (Bernhardt and Palmer 2007) that degrade the physical and chemical composition of instream water. While this pilot study provides a useful broad-brush overview of current conditions, expanding this effort is necessary in order to develop sufficient information to direct and guide restoration planning.

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